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General Mills, Inc.
Mechanical Division

ENGINEERING RESEARCH & DEVELOPMENT DEPARTMENT

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PROGRESS REPORT

HIGH ALTITUDE AIR SAMPLING

Contract Nonr 875(00) Annex XI

April and May 1954

Prepared for

Office of Naval Research
Washington 25, D. C.

Report No. 1309

Date: June 10, 1954

Prepared by: G. R. Whitnah

Approved by:

Cledo Brunetti

Cledo Brunetti, Director

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Mechanical Division
ENGINEERING RESEARCH AND DEVELOPMENT DEPARTMENT
2003 East Hennepin Avenue
Minneapolis 13, Minnesota

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SUMMARY

Progress has been made toward the objectives of the research phase of this project. During the period covered by this report three balloon flights were made in addition to laboratory work.

A motor test flight to an altitude of 96,000 feet was successfully completed on 8 April. Performance information was telemetered during flight and independently recorded by instruments aloft. The performance of three air sampling motors tested was satisfactory for the project requirement at that altitude. Brush wear over an 88 minute operating period was satisfactorily low for motors operating in ambient air, pressurized chamber and humidified environment. The very low power requirement atthat altitude resulted in good brush performance. Detailed presentation of the data and results of this flight is given in section II of the report.

A high altitude air sampling flight on 6 May did not result in the collection of a sample because of rupture of the 1161 balloon on ascent. A new tailored tapeless balloon of 126.5 feet diameter has been designed for this requirement and will be flown in June to carry air sampling equipment to 98,000 feet.

A test flight of the new 60 foot tailored tapeless balloon was successfully made on 25 May. The new automatic controls for future use at 50K, 65K, 80K and 100K were used and successfully programed the flight. Measurements of circumferential stress on the balloon during flight were made and indicated that aerodynamic forces during ascent can cause definite circumferential tension in a balloon. The magnitude of this tension was low, reaching a maximum of approximately 10% of the material strength. Temperatures of helium, polyethylene film and ambient air were telemetered in addition to the stress information on the experimental flight. Data indicate that helium temperature during daytime ascent is generally lower

than air temperature and film temperature is slightly higher than gas temperature, both effects being diminished by heat transfer from the balloon.

A comparison has been made of the variables involved in operation of a sampling system utilizing compression and storage of air in a metal vessel at elevated pressure. Estimates of power and weight are summarized in figure 18 of section II. This type of sampling system appears feasible and would have definite advantage particularily if a high rate of sampling activity was required.

The status of the work is encouraging. Much information has been gained during this period which will advance knowledge of the problems involved in high altitude air sampling.

Work in the near future will be centered generally on the completion of the objectives outlined in the March report. It will involve, specifically, the high altitude air sampling flight, further battery tests, improvement of stress measuring techniques and preparation of equipment for regular flights for July.

I. AIMS

The aims of the research phase were outlined in the March report. They included investigation of electric motor operation at high altitude, development of new automatic controls, design of a new balloon, sampling at high altitude, measurement of temperatures during flight, testing of battery performance and study of air sampling by compression and storage.

In addition to these objectives, authorization has been given to investigate stresses in balloon material during flight. This work has been initiated and is described in section II of this report.

II. WORK ACCOMPLISHED

During the period covered by this report, progress has been made toward all objectives. Three balloon flights were made in addition to laboratory experimentation and analysis.

A. The motor test flight was successfully completed on 8 April 1954. This equipment was launched from Pierre, S. D. at 0533 CST and impacted near Portage, Wisconsin at 1751 CST. Figure 1 is the time-altitude curve for this flight, giving significant information.

As described in the report for March, the primary objective was to obtain high altitude performance information on the direct current air sampling motors that have been used on this project. Past experience revealed that motor brushes were frequently badly worn after 35 minutes of operation on the 80K air sampling flights. Since the sampling flight to higher altitude requires a 55 minute operation cycle, the suitability of these motors was open to question.

Three motors were carried to 96,000 feet, where they operated from storage batteries for a period of 88 minutes.

One motor ran in open air with no change from previous practice. The second motor was enclosed in an aluminum housing equipped with a high speed shaft seal. An air storage tank with pressure regulator maintained a pressurized atmosphere around the motor. The third motor was enveloped in an insulated bag, lined with polyethylene. Saturated sponges provided a water vapor atmosphere around the motor.

Information defining the performance of the motors was transmitted from the balloon during flight. A 40 megacycle system was used, in which an automatic selector switch allowed transmission of three motor speeds and one temperature measurement. Since the shaft seal on the pressurized motor was

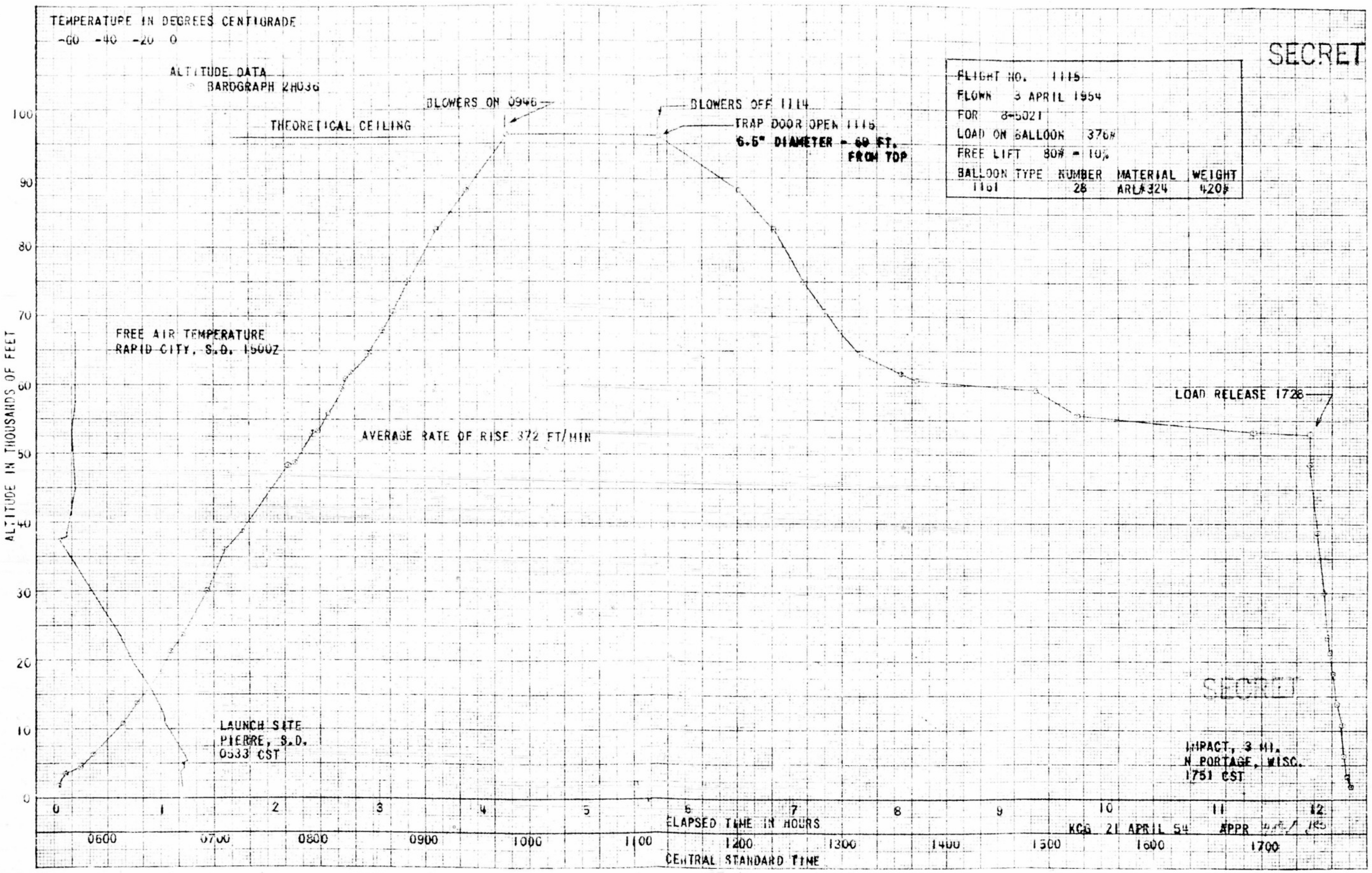

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Fig. 1

A-21-15 B

required to operate at 10,000 RPM, the temperature rise due to friction at this point was of value in determining the effectiveness of the unit. Figure 2 shows the transmitter with automatic selector switch.

Each circuit connected to the transmitter by the selector switch resulted in an audio frequency that was measured on the ground with a signal generator by observing lissajous patterns on an oscilloscope.

On each blower was mounted a small permanent magnet which rotated directly with the wheel. A pick-up (see figure 3) near the magnet introduced a signal of the same frequency as the blower motor.

A thermistor of proper resistance characteristic produced measurable audio frequencies in the transmitted signal.

Data from the telemetering are shown in Figure 4. Note that the speed of the pressurized motor was lowest, due to the additional frictional drag of the chamber shaft seal. The least variation in speed was found for the pressure motor. However, the speeds of all three motors were well within the allowable tolerance of the air sampling system requirement.

Data from the recording film are given in Figure 5. Calibration curves for speed indicators are shown in Figures 6,7, and 8. The average of the speed curves agree within 1% with the telemetered information. The battery voltage decreased slightly over the operation period, but did not result in an important speed decrease. Current draw for each motor was found to agree with previous laboratory measurements. The absolute pressure in the motor chamber was maintained at 4.0 psia by the regulating valve which admitted air from a storage resevoir. Ambient air temperature from the bi-metallic thermometer attained a minimum value of -27°C. Since this is considerably higher than expected stratosphere temperatures, it is believed that the bi-metal unit was affected by solar radiation.

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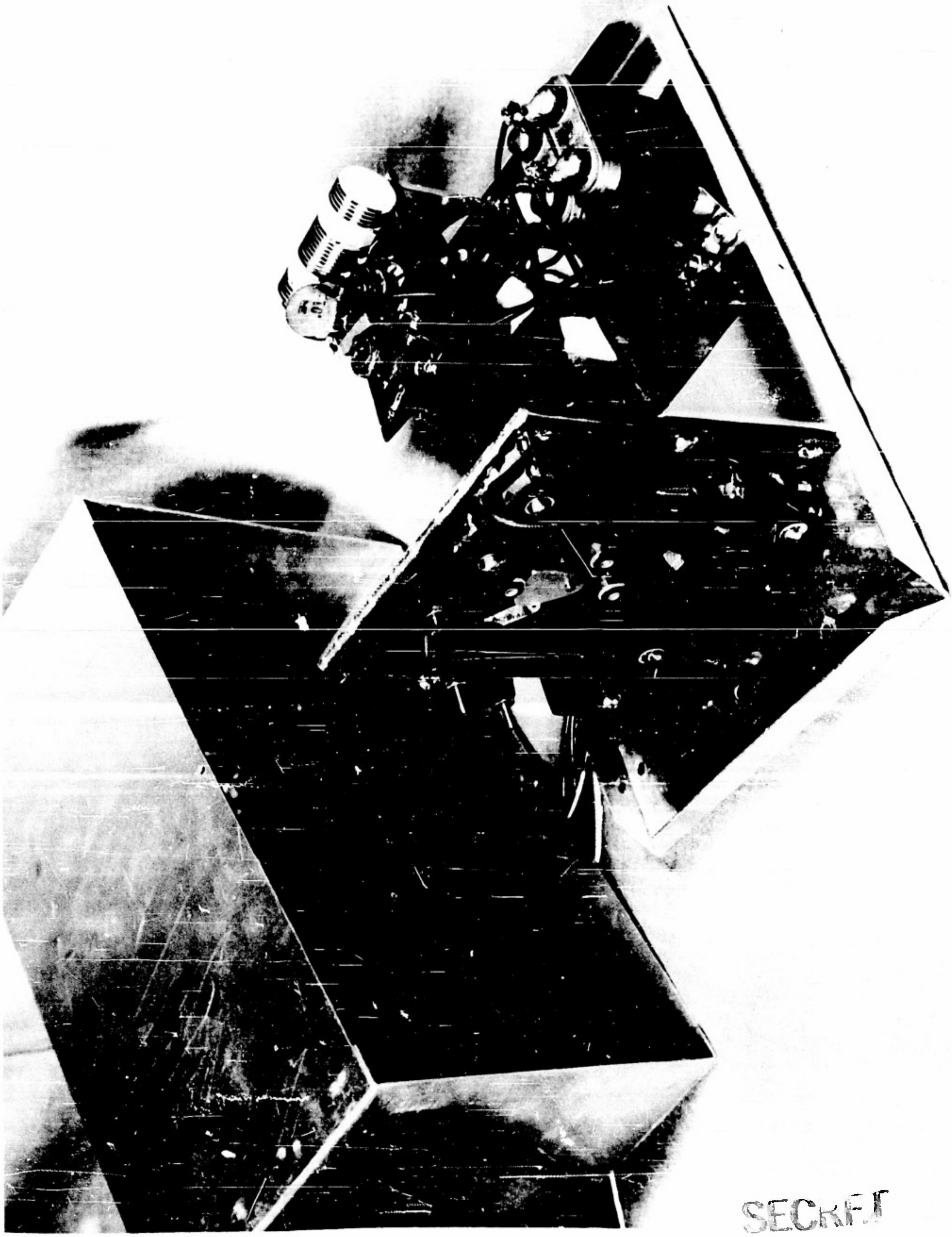

Figure 2 Transmitter with selector switch.

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Figure 3 Signal pick-up mounted on blower.

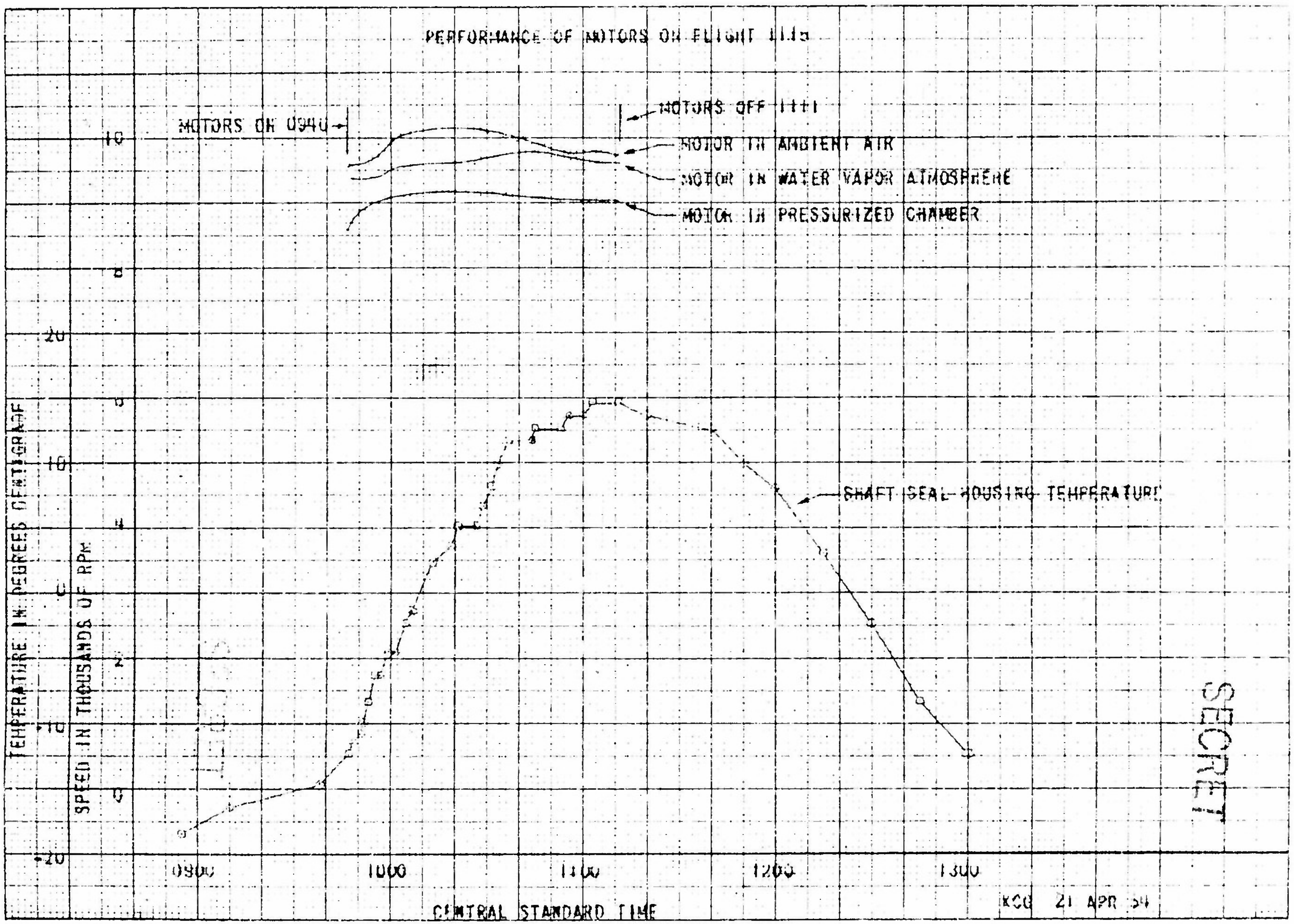

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Fig. 4

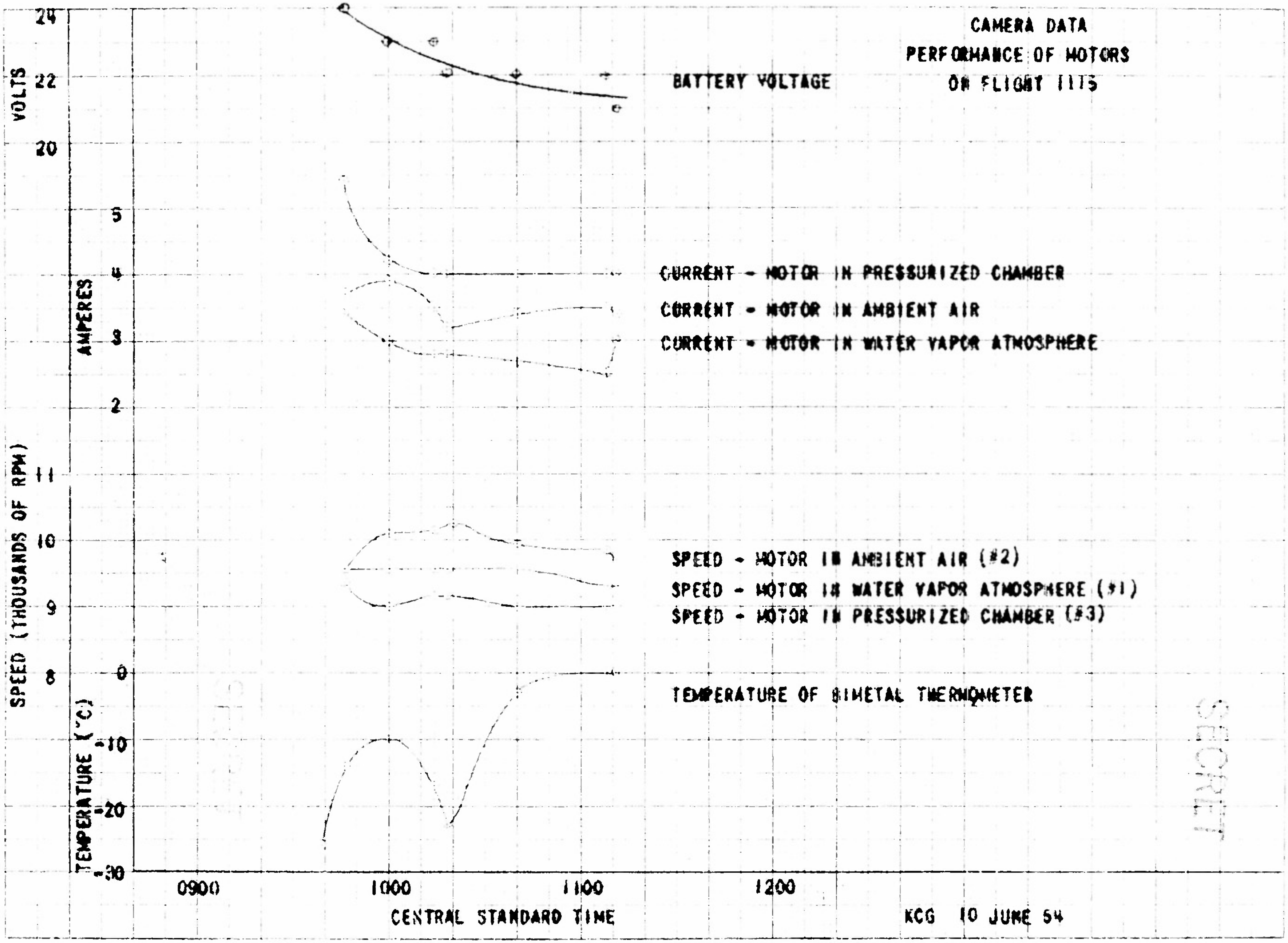

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Fig. 5

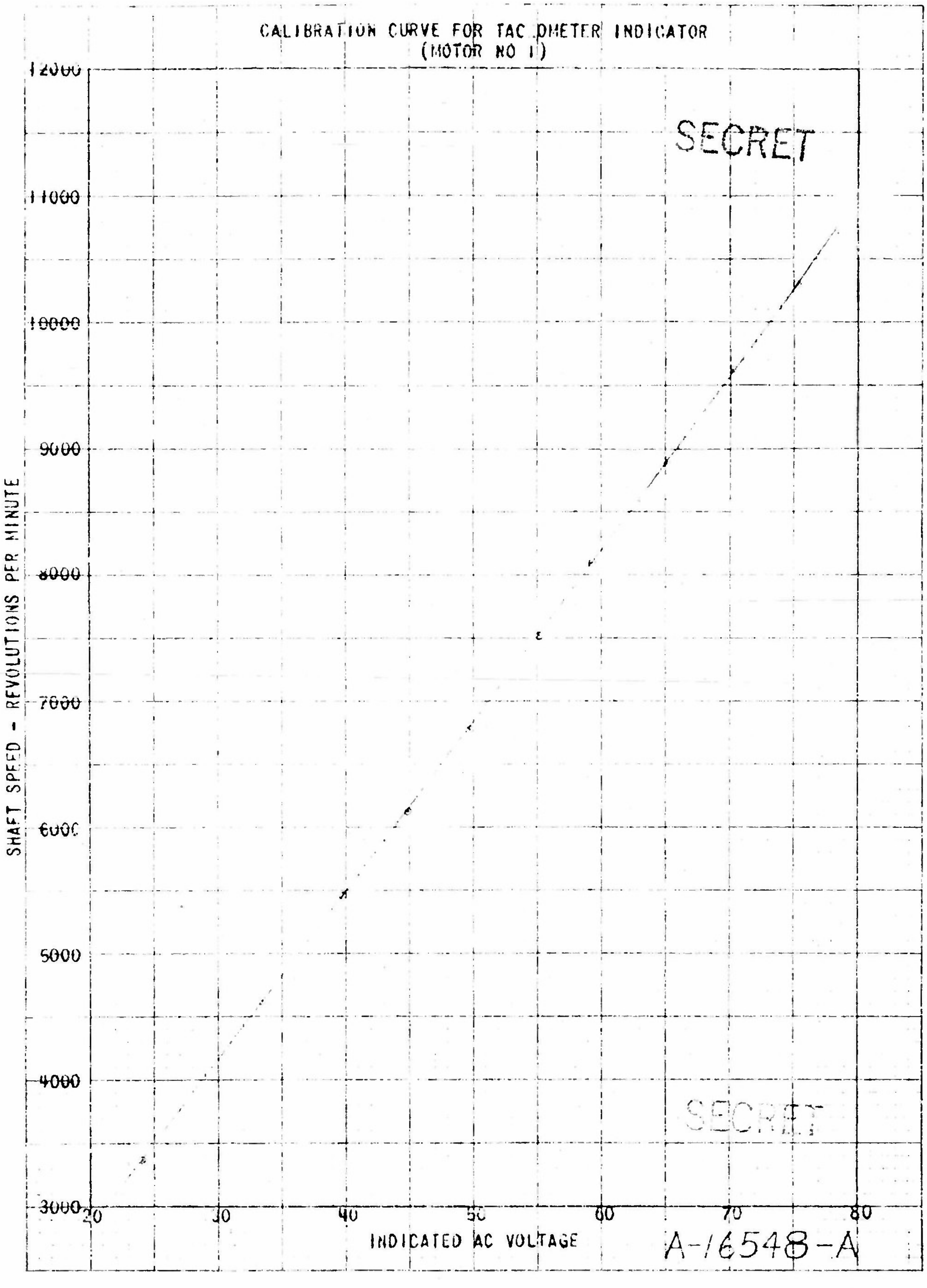
CALIBRATION CURVE FOR TACOMETER INDICATOR
(MOTOR NO 1)
SECRET
SHAFT SPEED - REVOLUTIONS PER MINUTE
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
20
30
40
50
60
70
80
INDICATED AC VOLTAGE
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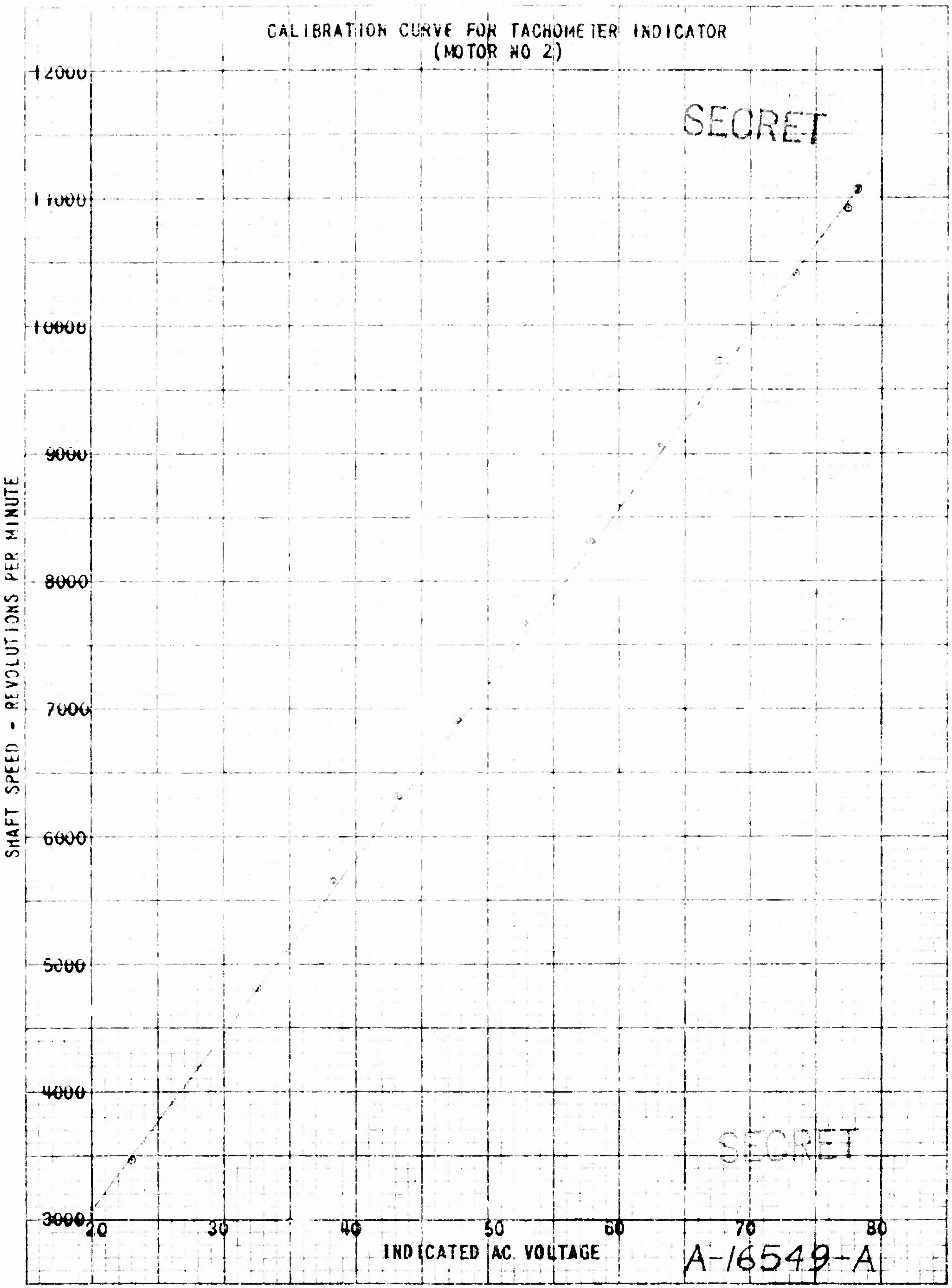
Fig. 6



CALIBRATION CURVE FOR TACHOMETER INDICATOR
(MOTOR NO 2)
SECRET
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
SHAFT SPEED - REVOLUTIONS PER MINUTE
20
30
40
50
60
70
80
INDICATED AC VOLTAGE
SECRET
A-16549-A

Fig. 7

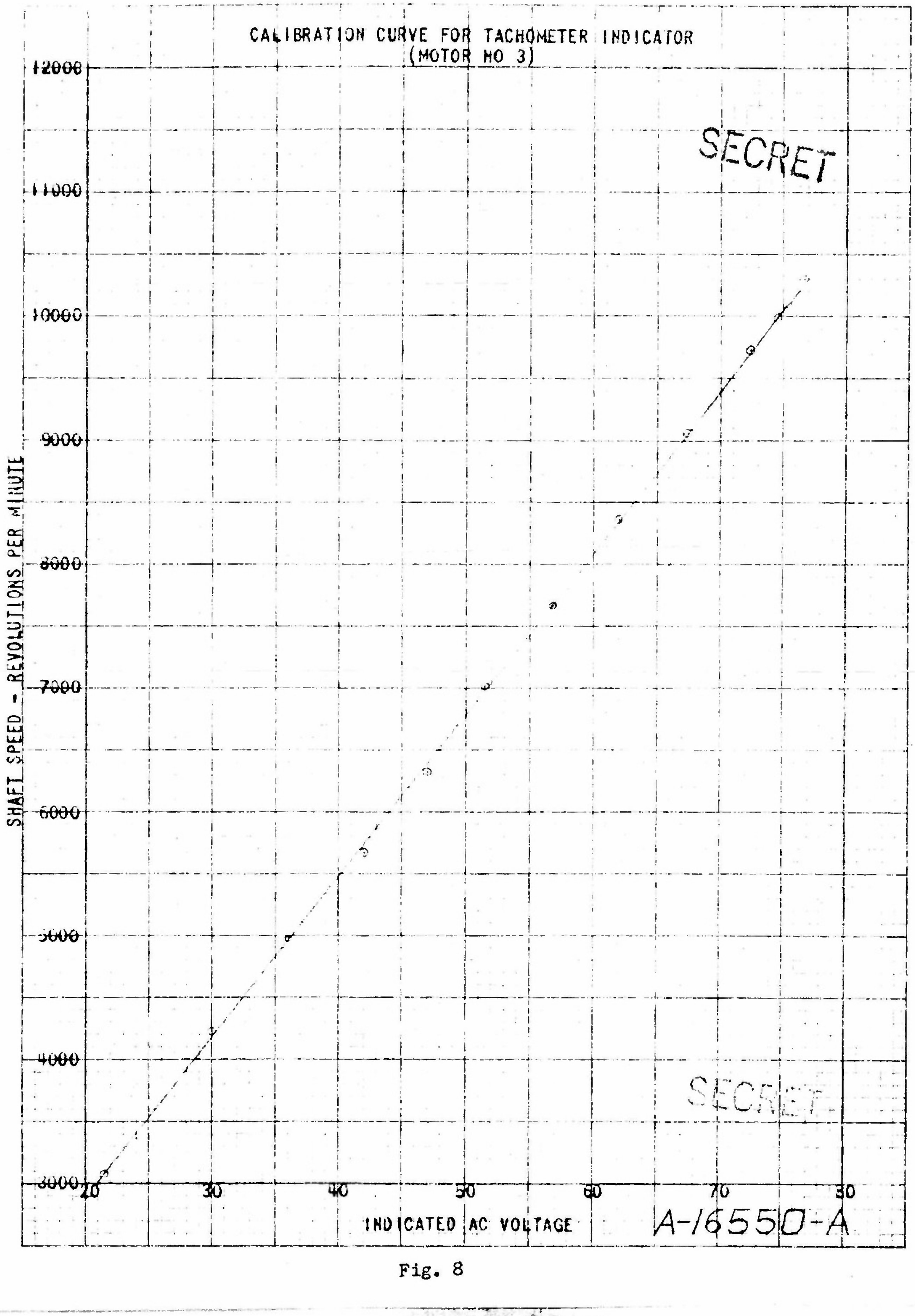

CALIBRATION CURVE FOR TACHOMETER INDICATOR
(MOTOR NO 3)
SECRET
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
SHAFT SPEED - REVOLUTIONS PER MINUTE
20
30
40
50
60
70
80
INDICATED AC VOLTAGE
SECRET
A-16550-A

Fig. 8

Further information was gained by inspection of the equipment of the recovery. The brushes from the motors were removed and were considered in equally good condition.

Because of the simplicity and light weight, the motors running in ambient air were chosen for the high altitude air sampling flight. The excellent performance of these motors can possibly be traced to the very low power requirement (and resulting low brush current-density) at the 96,000 foot altitude. Power required by the blower wheel varies directly with air density and is minimized at this altitude.

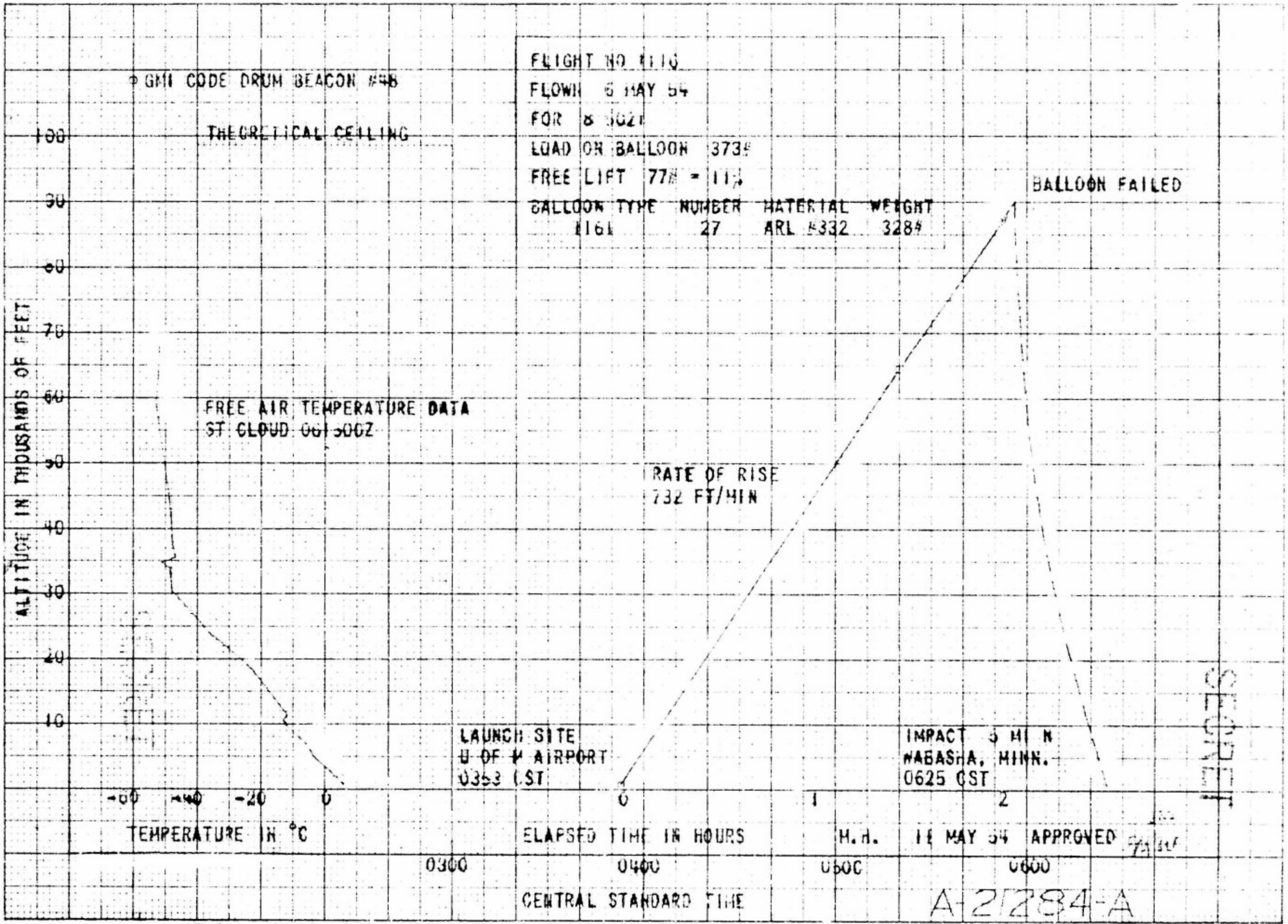
B. The high altitude air sampling flight was made on 6 May. A sample was not collected because the tow balloon ruptured on ascent at an altitude of 90,000 feet. Figure 9 is the time-altitude curve for this flight. Figures 10 and 11 were taken 1 minute apart by a camera suspended below the balloon.

A new balloon has been designed for this requirement. It is a tailored tapeless type to be made from 1.5 mil polyethylene. Diameter is 126.5 feet and the volume is 735,000 cubic feet.

The air sampling equipment will be flown on this balloon during June.

C. A test flight of the new 60 foot tailored tapeless balloon was successfully completed on 25 May. This balloon has been designed for use on the air sampling flights at 65,000 feet. Figure 12 is the time-altitude curve for this flight, No. 1117. Figure 13 is the gore pattern for the new balloon.

It is to be noted that the balloon floated very near the theoretical ceiling which was the desired sampling level. Descent was accomplished by



GENERAL MILLS, INC., ENGINEERING RESEARCH & DEVELOPMENT DEPARTMENT, MINNEAPOLIS, MINN.
Fig. 9

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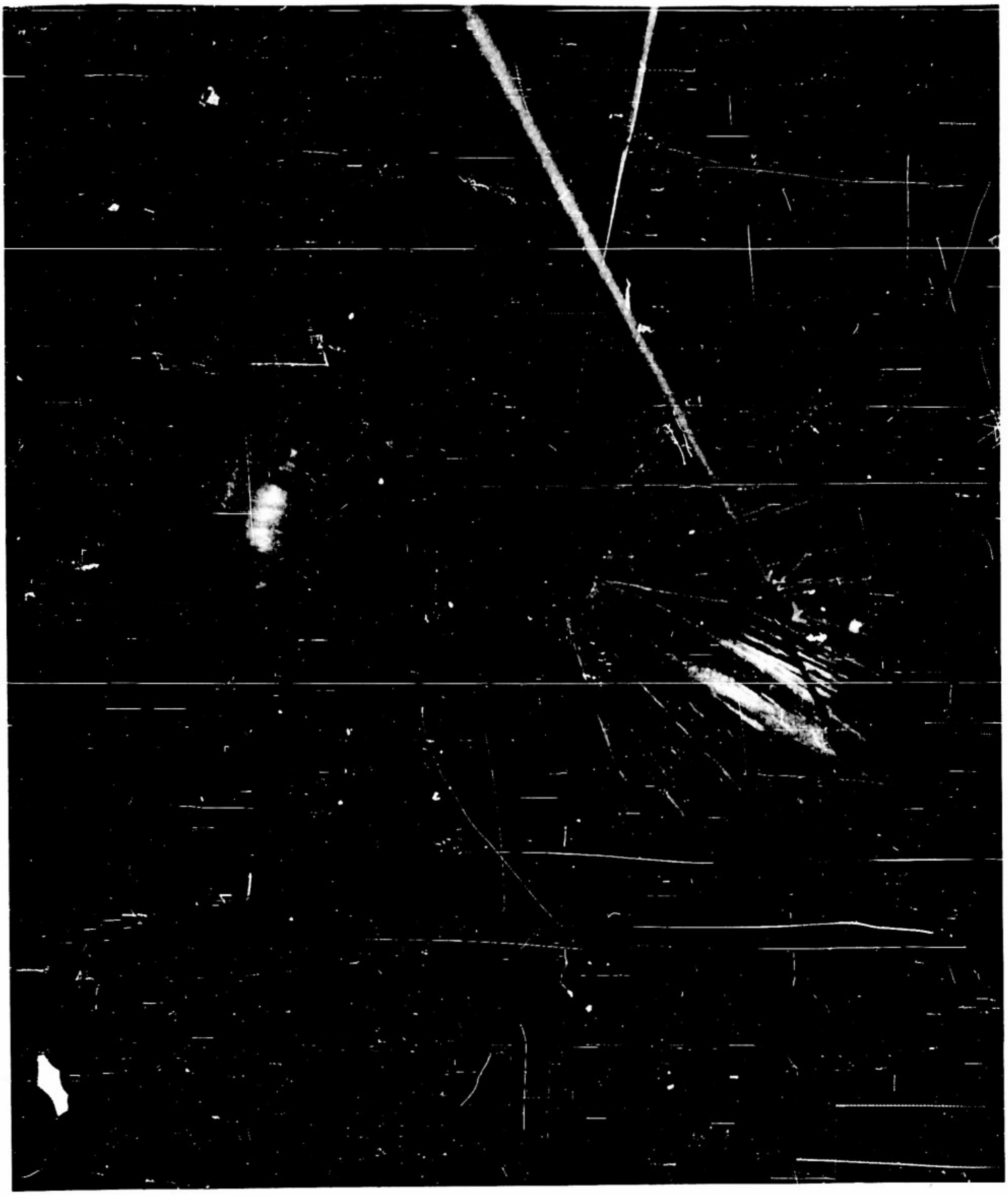

Figure 10 View of balloon at 90,000 feet before rupture.

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Figure 11 Balloon and parachute descending after failure.

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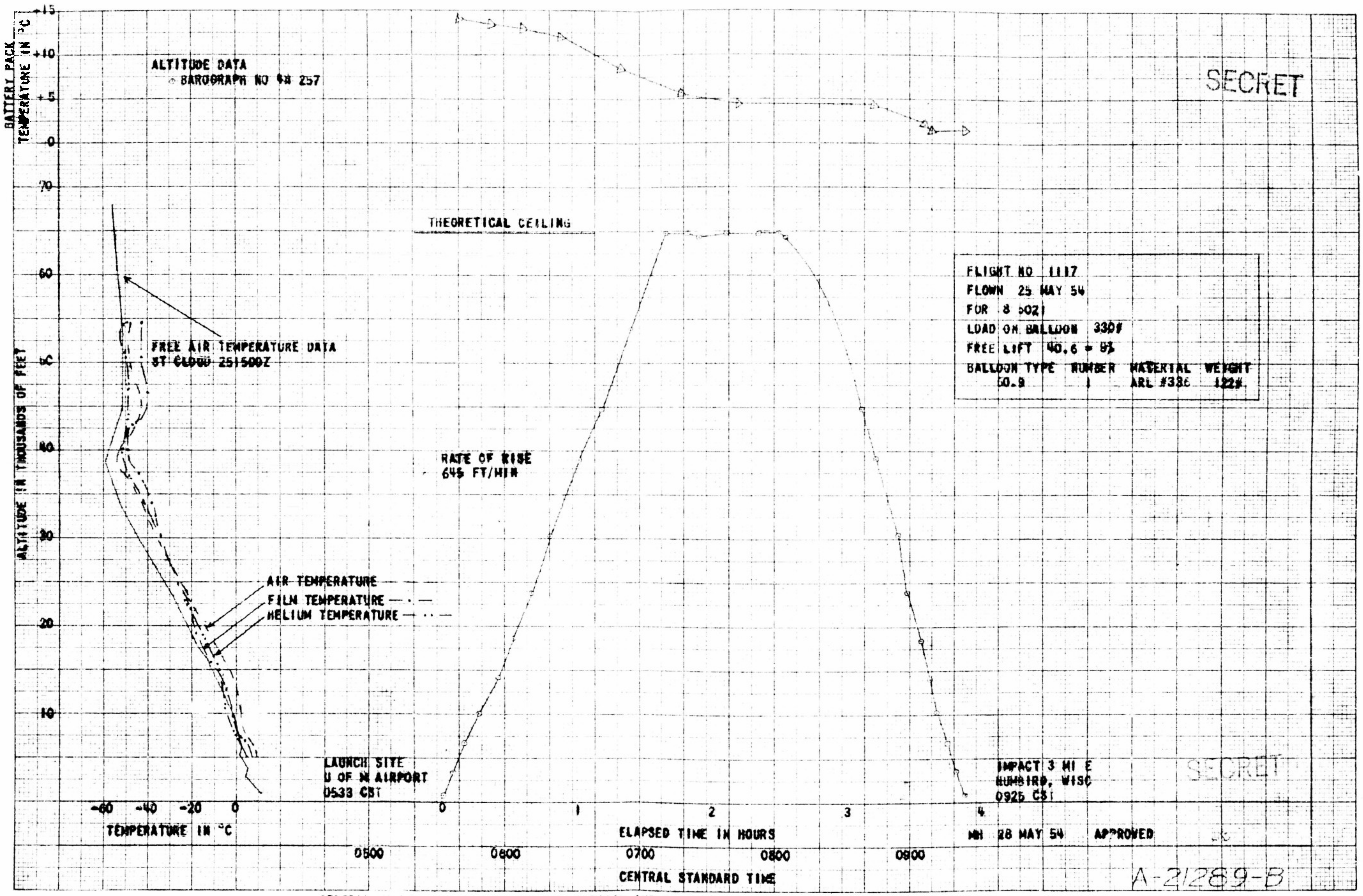

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Fig. 12

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FIGURE 13

4 April 1954
E. A. Coester

GORE PATTERN FOR N60,936 FT. DIA.
NATURAL SHAPE BALLOON
$\Sigma = .10; S_\lambda = 88.75$; VOL. = 92,024.54 FT.^{3}
OF GORES 22

Station # from Bottom	1/2 Gore Width in inches	Distance from Bottom along crease in feet and inches	
1	0	0	
2	4.486	3'	1.914"
3	8.152	5'	9.864"
4	11.224	7'	11.743"
5	16.410	11'	6.983"
6	18.949	13'	4.283"
7	23.922	16'	11.202"
8	27.983	19'	10.560"
9	30.553	21'	8.712"
10	34.888	24'	11.052"
11	38.233	27'	10.836"
12	41.123	30'	6.786"
13	43.845	33'	1.777"
14	46.841	36'	4.650"
15	48.621	38'	8.873"
16	50.522	41'	8.764"
17	51.465	43'	9.898"
18	52.210	46'	11.598"
19	52.179	49'	4.895"
20	51.419	52'	1.368"
21	49.746	55'	5.519"
22	47.480	58'	0.617"
23	44.165	61'	3.702"
24	41.275	63'	8.351"
25	37.808	66'	3.661"
26	34.158	68'	8.203"
27	29.504	71'	6.283"
28	24.987	74'	3.299"
29	18.554	77'	11.284"
30	14.341	80'	6.487"
34	0	88'	9.000"

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opening a trap door type valve in the balloon duct, as in previous project practice.

Several objectives were combined on this flight. The new automatic controls for the air sampling system were flown and successfully programed the flight operations. The new controls include in one unit the collection blower control, the transfer fan control and the radio beacon. Figure 14 is a view of this unit. Figure 15 shows the new control in the center, surrounded by the 3 units it will replace. A departure from the former control design is in the use of an electric timing motor rather then spring actuated time switches.

Because of a redesigned commutator bar, the pressure sensitive switches in the new unit are universally applicable to flights at 50K, 65K, 80K and 100K.

Measurements of circumferential tension were also made on Flight 1117. The determination of circumferential force during flight is considered valuable in analyzing balloon design and performance. The problem of obtaining significant information from stress sensitive devices by remote telemetering has been great. The use of conventional wire strain gages was ruled out after investigation, because of the small change in signal resulting from the minute forces encountered on the balloon.

Special stress measuring devices were built as shown in figure 16. Here a subminiture microswitch was mounted between two glass fiber tapes. A metal pressure plate on one tape actuates the switch when the tapes are subjected to tension. The "threshold tension" or triggering point for the unit was adjusted by changing the position of the clamps at either end of the force parallelogram. The minimum tension to close the switch was thereby adjustable from 5 oz. to 27 oz. Each unit was individually calibrated in the laboratory.

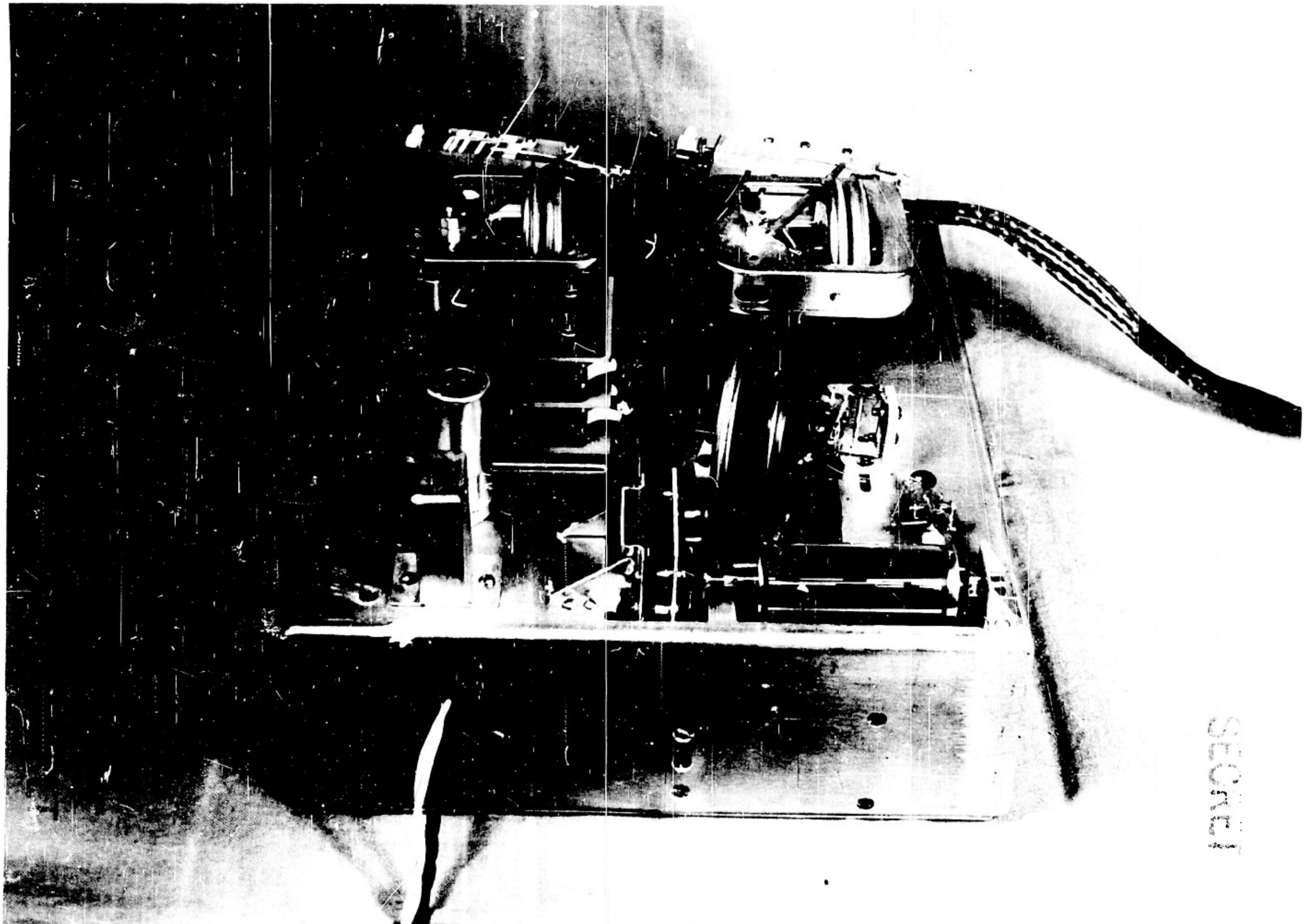

Figure 14. New control unit-pressure controls at top; altitude telemetering at bottom; programming cmas, left center.

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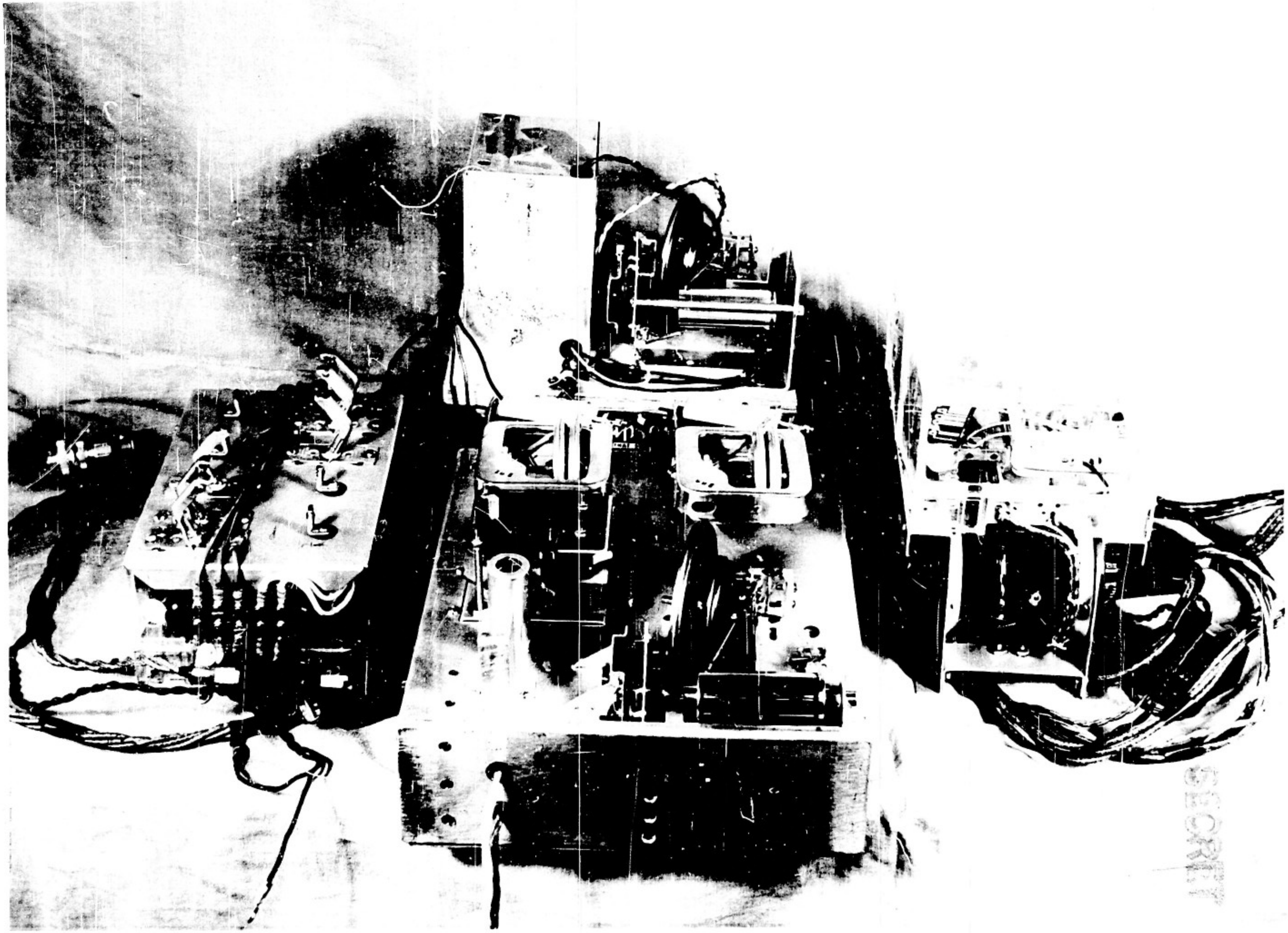


Figure 15. New control unit, center; surrounded by the units it will replace.

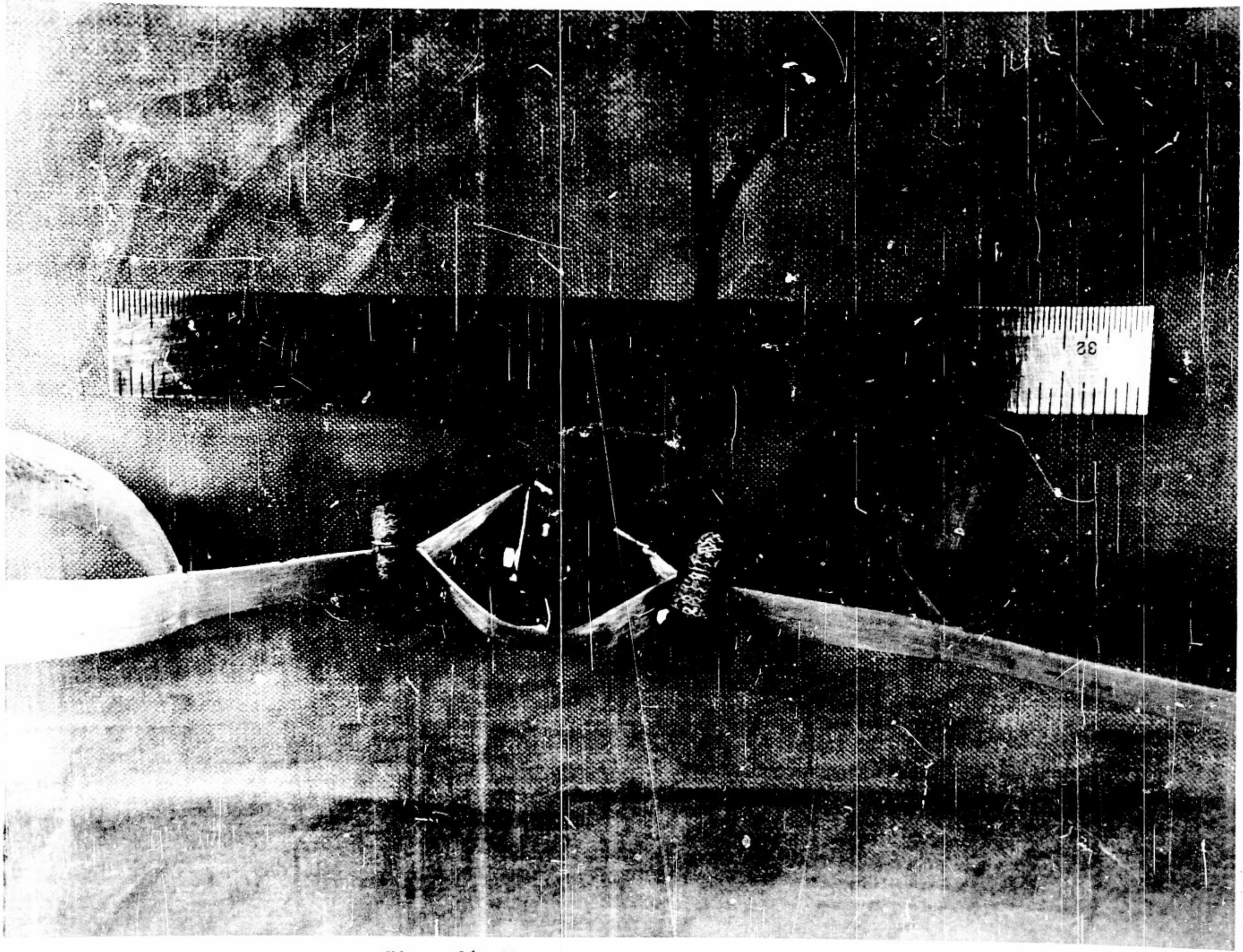


Figure 16 Stress measuring device. Tension closes microswitch to resistor.

These units were mounted on the balloon at two points, 15 feet and 20 feet from the top, in groups of 5 as shown in figure 17. They were applied to the balloon on equal spacing of 2½ inches, spanning a uniform slack portion, assured by a metal jig. Each of the five units in one area had different lengths between the end clamps and different minimum tension for actuation. Tapes placed on the ends minimized end effects.

Stress information was telemetered from the balloon by a 40 megacycle transmitter. The magnitude of the stress was determined by the audio frequency of the signal, measured on the ground. A frequency change was caused when each tension switch introduced a fixed resistor into the circuit. Since a force of a certain magnitude would close all switches of equal or smaller mimimum tension, the resistance of the circuit, and the resulting frequency, defined the tension.

The results determined from this system revealed that the balloon had no circumferential tension at the points of measurement when it was launched. The stress gages at the location 15 feet from the top indicated circumferential tension of 5 oz./tape or .13 pound per inch from altitude 21K to 34K. Then the tension increased to 7 oz/tape or 0.18 pound/inch from 34K to 43K. Above this altitude all switches relieved to less than the 5 oz. reading. The group of stress units placed 20 feet from the top showed no indication of tension above the minimum value of 6 oz./tape.

It is believed that the forces due to aerodynamic drag caused the circumferential tension. These forces would diminish at higher altitudes since they are function of air density. This could explain the reduction of the tension experienced in our measurements.

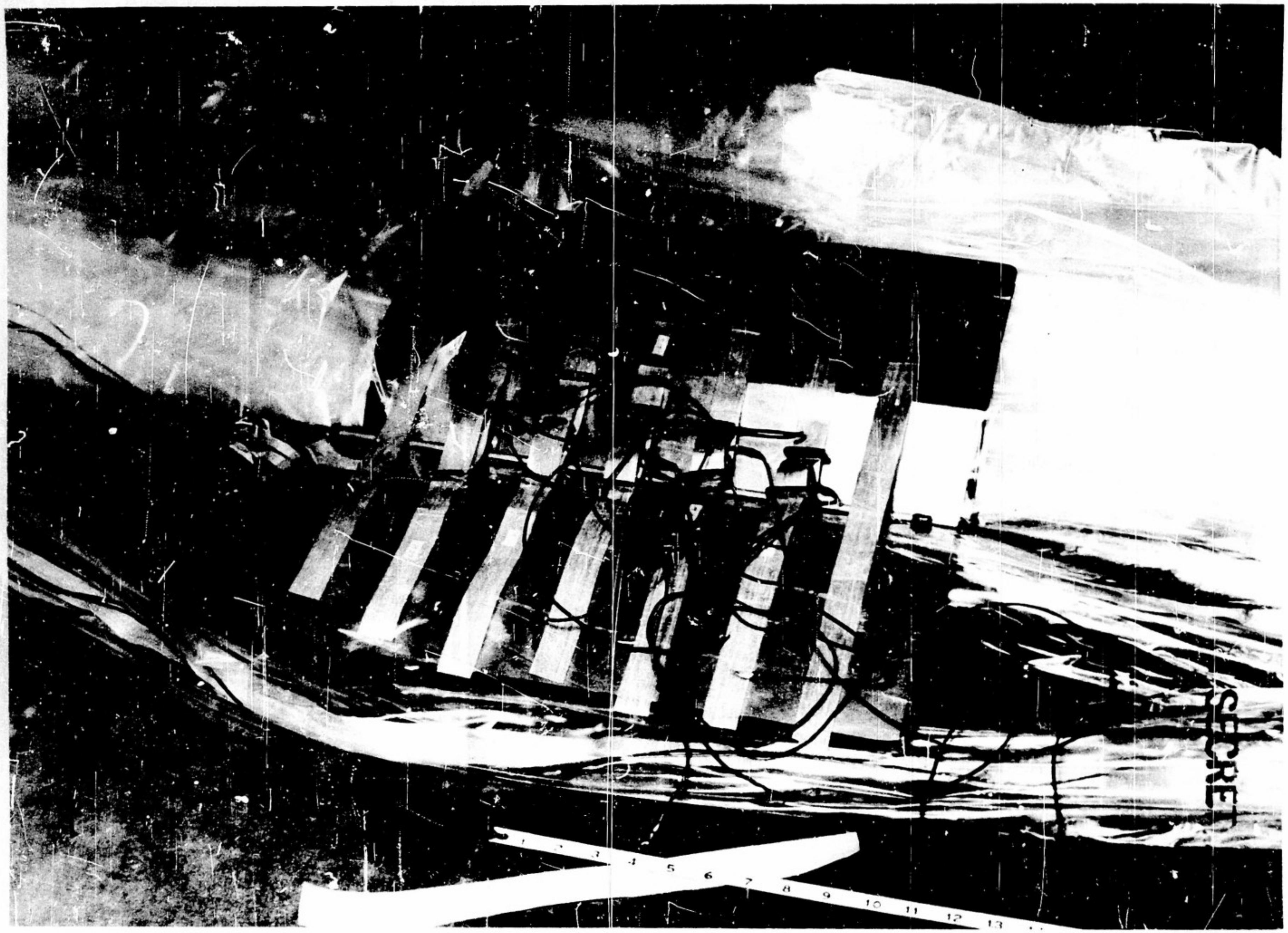


Figure 17 Stress measuring devices placed on balloon.

Determination of temperatures were made on Flight 1117. Air, helium and balloon film temperatures were telemetered using the 40 megacycle system which handled the stress information. Thermistors were automatically switched into the circuit which resulted in an audio frequency defining temperature. The thermistors for measurement of helium and air temperatures were shielded by pasteboard cylinders. The thermistor for measurement of polyethylene was taped to the balloon at a point 20 feet from the top.

The readings of these thermistors are plotted on figure 12. Valid temperature values were received only during the ascent of the balloon, since signal strength was low when the balloon moved away from the receiving station. The helium temperature was generally lower than the air temperature, due to the cooling by expansion. Transfer of heat kept the helium temperature within 5°C of the air temperature. The polyethylene film temperature was generally warmer than the helium temperature (by as much as 8°C), although it became nearly 2°C cooler than the helium for a short period.

The temperatures measured during this flight show that heat transfer minimized the depression of helium temperature and the related reduction of the ascent rate. Also, the data show that solar radiation elevated the material temperature above the helium. However, the magnitude of this effect was quite small due to convection and radiation heat transfer.

D. Work has continued on the evaluation of a sampling system utilizing compression of the air and storage in a metal tank.

Given in the March report were analyses of adiabatic compression energy and storage tank requirements. This work was entirely theoretical and independent of the practical limitations involved in the proposed balloon system.

Below are further considerations which introduce the major limitations:

Tank Construction

The equations given in our March report on tank stress and weight are based on a thin spherical tank:

$$S = \frac{P\,D}{4\,T}$$

Where P = internal pressure, p.s.i.g.
D = diameter, inches
T = thickness, inches
S = stress, p.s.i.

$$W = \pi D^2 T dm$$

Where D = mean diameter of the tank, inches
T = thickness of the metal, inches
dm = density of the metal lbs./cu.in.
W = weight, lbs.

Design of a tank has been made based on the spinning of aluminum hemispheres, to be welded to form a sphere. An internal diameter of 48 inches has been selected as a basis for calculation. Total air sample is assumed to be 30 pounds.

At pressures below 15 atmospheres, use of the equation of state for a perfect gas involves an error of less than 1%. The required internal pressure based on an assumed storage temperature of 125°F is:

$$P = \frac{WRT}{V} = \frac{(30)(53.3)(585)}{\frac{\pi}{6}(40)^3(144)} = \begin{matrix}194 \text{ p.s.i.a. or} \\ 179.3 \text{ p.s.i.g.}\end{matrix}$$

In determination of the tank thickness, the aluminum alloy 56SO has been chosen. It has a yield strength of 22,000 p.s.i. An allowable unit stress of 11,000 p.s.i. has been assumed. From above,

$$T = \frac{P\,D}{4\,S} = \frac{179.3(48)}{4(11,000)} = 0.195 \text{ inches}$$

This thickness is within the range normally handled in the spinning process.

The tank weight, less fitting, is,

$$W = \pi D^2 Tdm = \pi(48.1)^2(.195)(.095)$$
$$= 134 \text{ lbs.}$$

This tank weight appears to be practical for use in the system under consideration.

Compression

The compression equipment for this system must be lightweight, have large volumetric capacity, and increase the pressure by a very high ratio. These requirements are not compatible with any one compressor design.

For high compression ratios the multistage reciprocating compressor is most suitable, but has very low volumetric capacity. Centrifugal machines are capable of high capacity for small machines, but are quite limited as to the maximum pressure ratio. The positive displacement rotary pump has characteristics between the other types. Relatively high displacement can be had with moderate pressure differentials.

Figure 18 shows a comparison of the variables at the altitudes of present sampling.

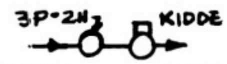
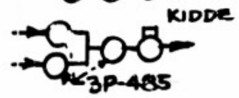
The 80,000 foot level requires a compressor capacity of 60.4 c.f.m. in order to collect a 30 pound sample in 3 hours.

The Kidde compressor which has been used at lower altitudes, with a capacity of 4.0 c.f.m., would require 45 hours of operation. However, combination of this compressor with positive displacement rotary types appears to be practical.

FIGURE 18

COMPARISON OF VARIABLES

Compression of Air at High Altitude

Altitude	Expansion Factor	Specific Volume	Weight Flow Rate, lb/min	Volume Flow Rate, c.f.m.	Suggested Flow Diagram
Sea level	1.00	13.1	0.167	2.2	
50,000 ft.	6.59	86.3	0.167	14.4	
65,000 ft.	13.49	177	0.167	29.5	
80,000 ft.	27.62	362	0.167	60.4	

Altitude	Estimated Power, H.P.	Required Energy, HP, HRS.	Silvercell Wt.- Lb.	Compressor Wt.- Lb.	Tank Wt-Lb	Controls & Misc Wt-Lb	Estimated Total Wt. Lb.
50,000 ft.	2.3	8.2	122	65	134	50	371
65,000 ft.	3.3	11.2	168	80	134	50	432
80,000 ft.	3.8	13.4	200	95	134	50	479

The suggested flow diagrams shown in figure 18 are based on estimated performance of Pesco aircraft vacuum pumps. The required energy listed is based on extrapolation of performance figures for the machines involved.

The total payload weight estimates of 371-479 pounds given in figure 18 indicate that this system is definitely feasible but would require somewhat larger balloons than are now used at these altitudes.

III. STATUS

With the completion of the work described in section II, considerable information has been accumulated which can contribute to air sampling work.

The motor performance data gathered open new possibilities in very high altitude sampling work. The motor brush problems have been shown to diminish rather than increase with altitude for the particular demands of this project.

The stress measurement work has confirmed the belief that severe circumferential tensions do not normally exist in the natural shape balloons. The measurement of circumferential stresses of the magnitude detected brings to view the possible detrimental effects of high rate of rise and the accompanying aerodynamic forces.

Successful operation of new automatic controls brings a greater degree of interchangeability which should prove valuable in carrying out the sampling work in the future.

The feasibility of an air sampling system based on compression and tank storage has been supported by analysis and investigation of available components. A system of greater adaptability could be developed from this preliminary work .

IV. FUTURE WORK

The high altitude sampling flight is the effort of first importance for the month of June. The sampling equipment to be used is as described previously with the exception of the 126.5 foot tailored tapeless balloon.

The improvement of the stress measuring technique to permit a greater number of measurements will be valuable. Determination of meridional tension in addition to circumferential tension will present a more complete picture of the forces acting on the balloon material. A test of the 60.9 foot tapeless balloon at a high rate of ascent will be made with stress measurements to be telemetered during flight.

The battery performance testing will be continued in order that the most suitable units will be available for regular air sampling flights during the July-October period.